Wave-Current Interaction in Coastal Inlets and River Mouths

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LONG-TERM GOALS

The wave-driven dynamics of coastal areas are important for circulation and mixing, transport processes, and accessibility by vessels. The long-term goal of this study is to improve our understanding, observational capability, and model representation of wave-current interaction in complex coastal inlets, and determine the role of nonlinearity on wave statistics in such areas.

OBJECTIVES

The specific objectives of this study are to: 1) develop observational capability using wave-resolving Lagrangian drifters to study wave-current interaction, and contribute to a comprehensive community data set of coastal inlet and river mouth processes, 2) determine the role of nonlinearity in wave-current interactions by comparing observations to theoretical models and Monte-Carlo simulations, and 3) develop predictive modeling capability of wave statistics in a complex coastal environment with strong currents.

APPROACH

To better understand interactions between waves, currents and topography in a coastal inlet, and improve predictive capabilities, we propose an integrated study that combines field observations with newly developed observational capability of waves and surface currents using wave-resolving Lagrangian drifters with advances in theory and modeling capability of wave-current interaction, nonlinear focusing and wave dissipation. The modeling effort will include the development of a spectral model [Janssen & Herbers, 2009], suitable for nonlinear random waves in finite depth over variable currents (figure 1).

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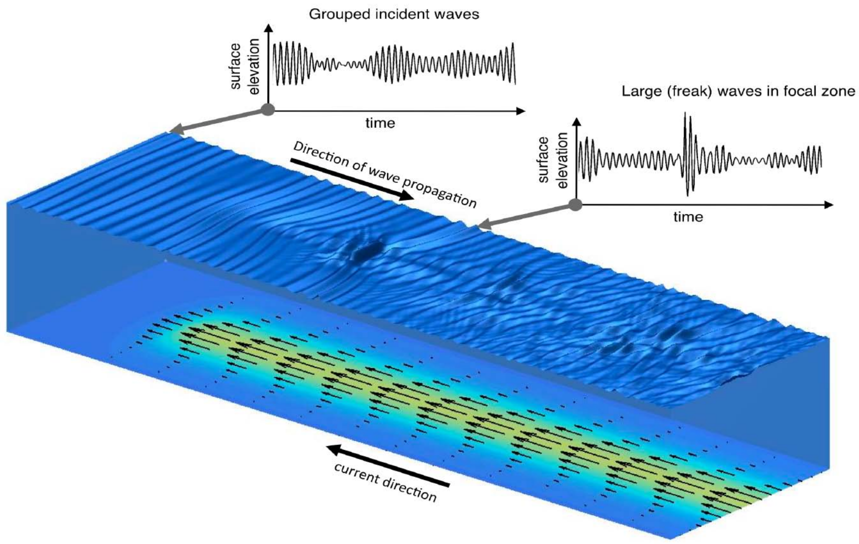

Figure 1 Model prediction of waves propagating over an opposing current jet (ebb tidal flow scenario) [Janssen & Herbers, 2009]. Nonlinear effects in a wave focal zone result in frequency-downshift, non- Gaussian statistics, and an enhanced likelihood of extreme (freak) waves (see time series inset).

WORK COMPLETED

The planning phase of the project is now nearly completed. The DRI research team has determined the field site for the 2011 summer main field experiment (New River Inlet, NC). Additionally, we have identified a site for our instrument development and deployment strategy testing, and a potential site for a wave-current experiment in collaboration with other DRI research teams. We have continued testing and developing the free-drifting Lagrangian wave buoys, and have continued the development of a spectral model for wave-current interaction.

The principal objective for the one-year planning phase was the identification of the main DRI field site (New River Inlet, NC), a local site for instrument development and testing (San Francisco Bay, CA), and a more exposed site for studying wave-current and wave-bottom interaction in relatively energetic wave conditions (Muskeget Channel, MA). These tasks have been nearly completed and the sites and their characteristics are briefly summarized in the following.

New River Inlet, NC

The field site for the summer 2011 field experiment is the New River Inlet in North Carolina (see figure 2). The offshore bathymetry consists of a nearshore tidal bar extending to about 4m of water depth. We plan to deploy long-term moored instruments offshore of the 8m-depth contour, to provide offshore boundary conditions of waves and currents for the DRI teams, and to deploy drifters and short-term moorings in 4-8 m depth to study wave and current dynamics in the nearshore.

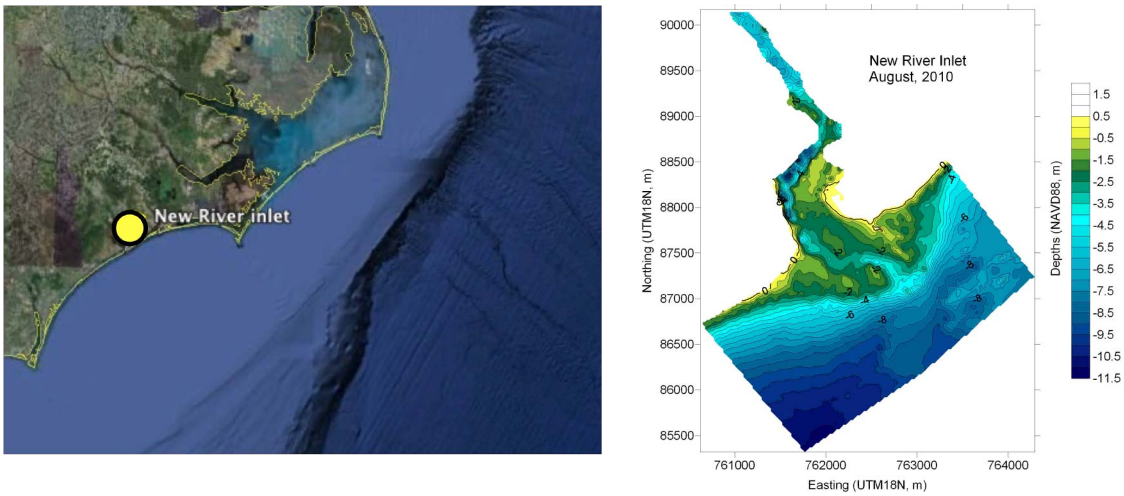

Figure 2. New River Inlet, North Carolina. This site will be the focus of the main DRI summer 2011 field experiment. Bathymetry data courtesy of USACE Field Research Facility and Jesse McNinch.

Raccoon Strait, San Francisco Bay

Deployment of instruments in strong currents and energetic seas is challenging and the optimal deployment strategy for free-drifting wave buoys in such conditions is not yet established. To test and develop our instruments for such conditions, and optimize deployment strategies of buoys and moored instruments in strong currents, we have identified a local site characterized by strong wave-current interaction that is easily accessible by small vessels. Raccoon Strait in San Francisco Bay is the passageway between the Tiburon Peninsula and Angel Island (see figure 3), characterized by strong tidal currents. Near the south-west end of the Strait, a shallow sill (~10m depth) results in enhanced current speeds on the ebb tide so that waves radiating into the Bay through the golden gate (and locally generated wind waves) are sometimes completely blocked in this area. The combination of strong currents, wave blocking, and the availability of marine facilities at the nearby Romberg Tiburon Center (see figure 3) makes this an outstanding site for testing and instrument development. We plan to do several short-term deployments of drifters to test different strategies and continue instrument development. These observations will also provide unique and valuable information on wave-current interaction, wave blocking, and nonlinear wave statistics in a current-induced focal zone.

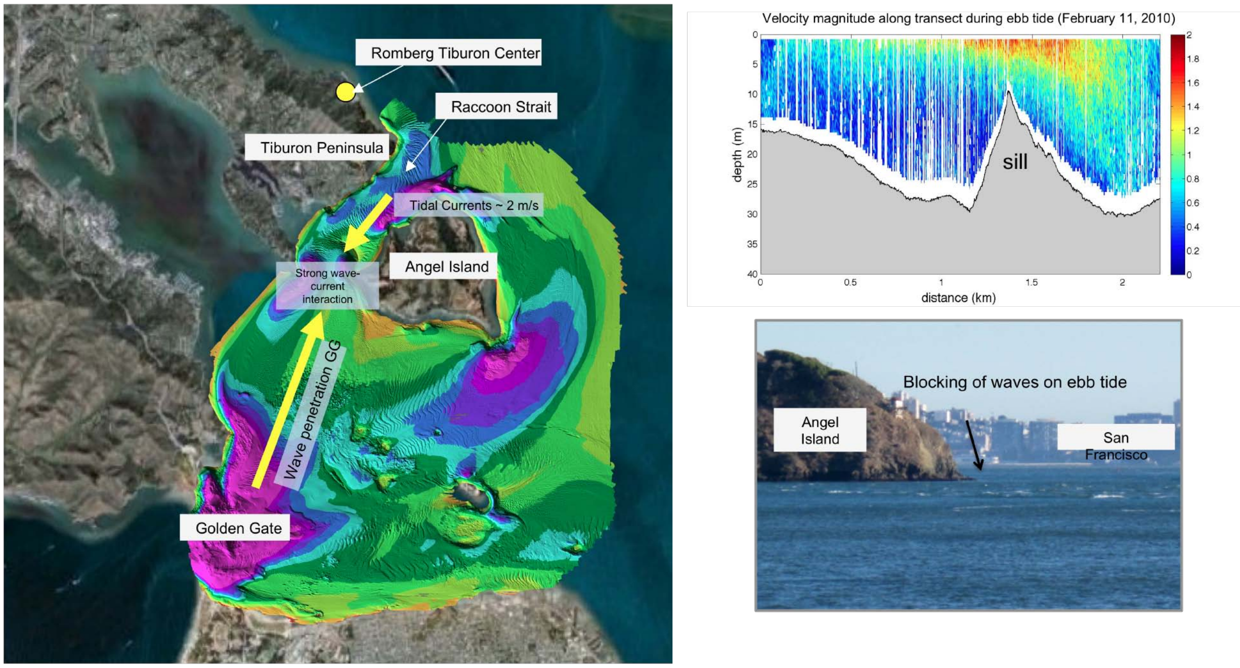

Figure 3. Raccoon Strait, San Francisco Bay. Strong ebb tidal currents through the Strait result in wave-current interaction (and blocking) near the western tip of Angel Island. The proximity to the Romberg Tiburon Center makes the site easily accessible by small vessels. This site will be used for instrument development and field testing. Bathymetry data courtesy of the Seafloor Mapping Lab of California State University Monterey Bay.

Muskeget Channel & Wasque shoals, Martha's Vineyard

The inlet area between Martha's Vineyard and Nantucket, consists of the Muskeget Channel and the connected Wasque shoals (figure 4). Strong tidal currents, moderate wave energy, and the proximity to the Woods Hole Oceanographic institution, makes this a potential site for studying wave-current interaction in a coastal inlet.

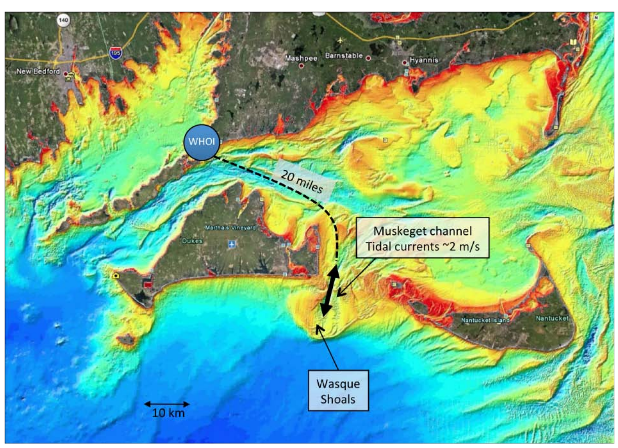

Figure 4. Muskeget Channel & Wasque shoals. This inlet area is characterized by strong tidal currents. The proximity of Woods Hole Oceanographic Institution makes this a potential site to study wave-current interaction. Data courtesy of USGS and Peter Traykovski (WHOI).

RESULTS

A central part of our research plan for the Tidal Inlets and River Mouths experiments is the deployment of a large array of GPS-tracked drifters that both measure the ocean surface wave orbital motion and the ambient surface current. This plan was motivated by pilot tests in the ONR High-Resolution Air-Sea Interaction (HiRes) DRI where we found that relatively inexpensive SBAS-enabled GPS receivers can resolve the vertical and horizontal orbital wave motion (see our FY09 annual report for a preliminary field validation based on independent measurements on the same buoy from an accelerometer/tilt/compass sensor system). During FY10 we built a prototype buoy (figure 5) equipped with a Magellan Mobile Mapper CX GPS receiver, an active external antenna for enhanced position accuracy, and a radio modem for real-time position tracking from a nearby vessel.

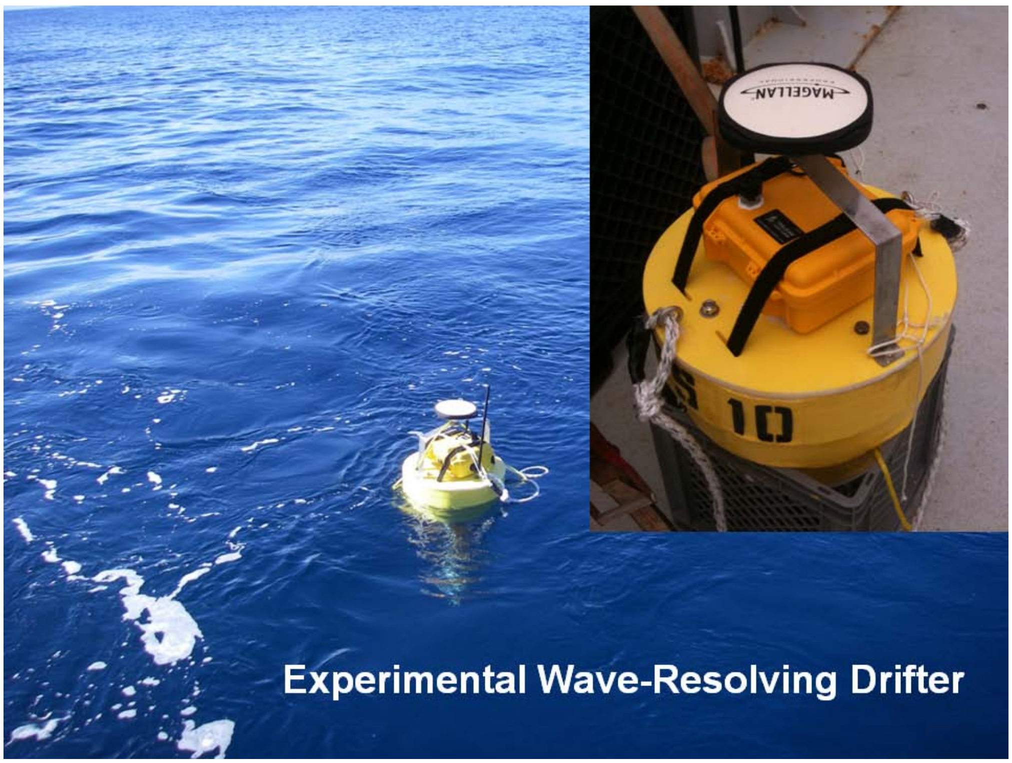

Figure 5. Prototype GPS drifter for Lagrangian wave and current measurements. The Magellan Mobile Mapper CX GPS receiver is housed inside the case on top of the 45 cm diameter drifter. Ballast chain is attached below the drifter to provide a stable platform for the external antenna attached to the metal bar. An additional antenna is attached to the side of the case for a real-time telemetry data link.

During the main HiRes experiment off the California coast near Bodega Bay we deployed the new prototype GPS drifters in close proximity to free drifting Datawell Directional Waveriders to evaluate the accuracy of wave measurements in a range of conditions. An example inter-comparison of the drifter with three different types of Datawell buoys (including both a conventional waverider buoy with an autonomous accelerometer/tilt/compass sensor package and the newer buoys that use a specialized GPS system) is shown in figure 6. These observations were collected in a moderately

energetic (significant wave height Hs = 1.8m) north-westerly wind sea in the presence of a weak south-west swell The drift tracks of the drifter and buoys (which vary in size from 40 to 90 cm diameter) are in good agreement indicating that they are advected by approximately the same 0.7 m/s surface current velocity. Estimates of the surface height spectrum and the mean direction and directional spread (as functions of frequency) agree well, demonstrating that the relatively inexpensive GPS drifter can provide accurate estimates of surface wave frequency and directional spectra comparable to those obtained from other single-point measurement systems.

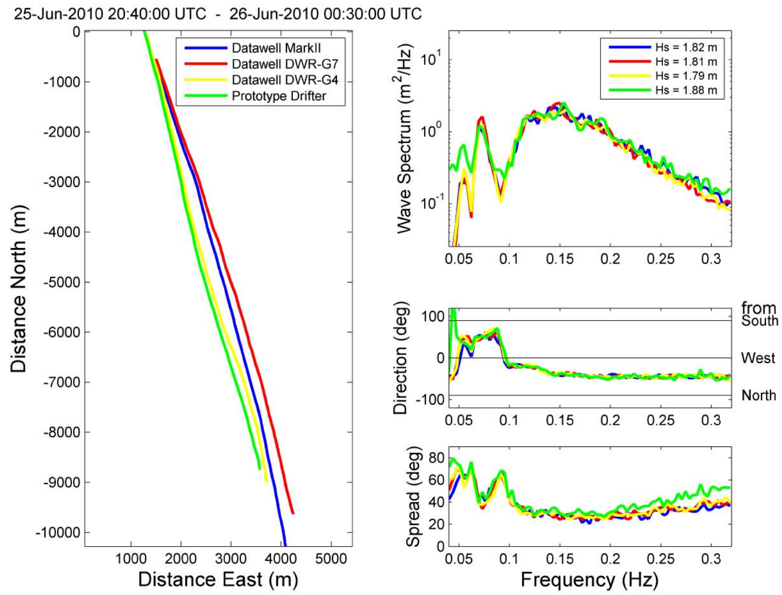

Figure 6. Inter-comparison of free drifting Datawell buoys (a 90 cm diameter accelerometer-based MKII and GPS-based 70 cm DWR-G7 and 40 cm DWR-G4) and our prototype GPS drifter during a 4-hour deployment when the buoys and drifter remained in close (less than 1.5 km) proximity of each other. Left panel: drift tracks. Right panels from top to bottom: surface height spectrum and mean direction and directional spread (as functions of frequency). Estimates of the significant wave height are listed in the legend of the upper right panel.

IMPACT/APPLICATIONS

The development of inexpensive, GPS-tracked drifter buoys will extent observational capability to areas where it is difficult to deploy and maintain moorings (such as in strong currents and/or energetic waves). This will contribute to improved understanding of the dynamics in coastal wave focal zones and the statistics of ocean waves in such areas.

The observations of wave-current interaction, wave focusing, and wave blocking in coastal areas will improve our understanding of wave statistics in such dynamic areas, and improve our understanding of nonlinear focusing effects in finite depth. The observations will be critical to validate theory and models, either existing, or those developed within the scope of this study.

RELATED PROJECTS

The development of the GPS-tracked drifter buoys was started as part of the ONR HiRes DRI to enable deployment of a greater numbers of instruments to capture the spatial variability (inhomogeneity) of waves and currents. The instrument development and deployment strategies planned in the present project build on our findings during the HiRes DRI.

REFERENCES

Janssen, T. T. & T. H. C. Herbers (2009) Nonlinear wave statistics in a focal zone, *J. Phys. Ocean.*, **39**, 1948-1964.